Chapter 1
Introduction

1-1. Purpose

This manual provides technical guidance for performing precise structural deformation surveys of locks, dams, and other hydraulic flood control or navigation structures. Accuracy, procedural, and quality control standards are defined for monitoring displacements in hydraulic structures.

1-2. Applicability

This manual applies to all USACE commands having responsibility for conducting periodic inspections of completed civil works projects, as required under ER 1110-2-100, Periodic Inspection and Continuing Evaluation of Completed Civil Works Structures.

1-3. Distribution

This publication is approved for public release; distribution is unlimited.

1-4. References

Referenced USACE publications and bibliographic information are listed in Appendix A.

1-5. Scope of Manual

The primary emphasis of this manual is placed on the technical procedures for performing precise monitoring surveys in support of the Corps periodic inspection and dam safety programs. General planning criteria, field and office execution procedures, data reduction and adjustment methods, and required accuracy specifications for performing structural deformation surveys are provided. These techniques are applicable to periodic monitoring surveys on earth and rock-fill dams, embankments, and concrete structures. This manual covers both conventional (terrestrial) and satellite (GPS) deformation survey methods used for measuring external movements. This manual does not cover instrumentation required to measure internal loads, stresses, strains, or pressures within a structure--refer to the references at Appendix A for these activities. Example applications on Corps projects are provided at Appendix B (Deformation Surveys of Locks and Dams) and Appendix C (Monitoring Schemes for Concrete Dams). The manual is intended to be a reference guide for structural deformation surveying, whether performed by in-house hired-labor forces, contracted forces, or combinations thereof. This manual should be directly referenced in the scopes of work for Architect-Engineer (A-E) survey services or other third-party survey services.

1-6. Background

The Corps of Engineers has constructed hundreds of dams, locks, levees, and other flood control structures that require periodic surveys to monitor long-term movements and settlements, or to monitor short-term deflections and deformations. These surveys are usually performed under the directives of ER 1110-2-100, Periodic Inspection and Continuing Evaluation of Completed Civil Works Structures. In some USACE commands, these types of surveys may be referred to as "PICES Surveys" -- an acronym which derives from the ER directive.

a. Structural deformation. Dams, locks, levees, embankments, and other flood control structures are subject to external loads that cause deformation and permeation of the structure itself, as well as its foundations. Any indication of abnormal behavior may threaten the safety of the structure. Careful monitoring of the loads on a structure and its response to them can aid in determining abnormal behavior of that structure. In general, monitoring consists of both measurements and visual inspections, as outlined in ER 1110-2-100. To facilitate the monitoring of hydraulic structures, they should be permanently equipped with proper instrumentation and/or monitoring points according to the goals of the observation, structure type and size, and site conditions.

b. Concrete structures. It should be intuitive that deformations and periodic observations will vary according to the type of structure. Differences in construction materials are one of the larger influences on how a structure deforms. For example, concrete dams deform differently than earthen or embankment dams. For concrete dams and other concrete flood control devices, deformation is mainly elastic and highly dependent on reservoir water pressure and temperature variations. Permanent deformation of the structure can sometimes occur as the subsoil adapts to new loads, concrete aging, or foundation rock fatigue. Such deformation is not considered unsafe if it does not go beyond a predetermined critical value. Therefore, periodic observations are typically configured to observing relatively long-term movement trends, to include abnormal settlements, heaving, or lateral movements. Conventional geodetic survey methods from external points and of centimeter-level accuracy are sufficient to monitor these long-term trends. Highly accurate, short-term deflections or relative movements between monoliths due to varying temperature or hydraulic loading are more rarely required. These may include crack measurements or relative movements between monoliths over different hydraulic loadings. Relative movement deflections to the $\pm$0.01-inch accuracy level are common.

c. Earthen embankment structures. Earthen or embankment dams and levees obviously will deform altogether differently than concrete ones. With earthen dams, the deformation is largely characterized as more permanent. The self-weight of the embankment and the hydrostatic pressure of the reservoir water largely force the fill material (and in turn, the foundation, if it too consists of soil) to settle, resulting in a vertical deflection of the structure. The reservoir water pressure also causes permanent horizontal deformation perpendicular to the embankment centerline. With earthen dams, elastic behavior is slight. Deformation survey accuracy requirements are less rigid for earthen embankments, and traditional construction survey methods will usually provide sufficient accuracy. Typical surveys include periodic measurement of embankment crest elevations and slopes to monitor settlements and slope stability. For embankment structures, surveys accuracies at the $\pm$0.1 foot level are usually sufficient for monitoring long-term settlements and movements.

d. Long-term deformation monitoring. Depending on the type and condition of structure, monitoring systems may need to be capable of measuring both long-term movement trends and short-term loading deformations. Long-term measurements are far more common and somewhat more complex given their external nature. Long-term monitoring of a structure's movement typically requires observations to monitoring points on the structure from external reference points. These external reference points are established on stable ground well removed from the structure or its construction influence. These external reference points are inter-connected and termed the "reference network." The reference network must also be monitored at less-frequent intervals to ensure these reference points have not themselves moved. Traditional geodetic survey instruments and techniques may be employed to establish and monitor the reference network points.

1-7. Deformation Survey Techniques

a. Reference and target points. The general procedures to monitor the deformation of a structure and its foundation involve measuring the spatial displacement of selected object points (i.e., target points)

from external reference points that are fixed in position. Both terrestrial and satellite methods are used to measure these geospatial displacements. When the reference points are located in the structure, only relative deformation is determined--e.g., micrometer joint measurements are relative observations. Absolute deformation or displacement is possible if the reference points are located outside the actual structure, in the foundation or surrounding terrain and beyond the area that may be affected by the dam or reservoir. Subsequent periodic observations are then made relative to these absolute reference points. Assessment of permanent deformations requires absolute data.

b. Reference point network. In general, for concrete dams it is ideal to place the reference points in a rock foundation at a depth unaffected by the reservoir. Once permanently monumented, these reference points can be easily accessed to perform deformation surveys with simple measurement devices. Fixed reference points located within the vicinity of the dam but outside the range of its impact are essential to determination of the deformation behavior of the structure. Thus, monitoring networks in the dam plane should be supplemented by and connected to triangulation networks and vertical control whenever possible.

c. Monitoring techniques. The monitoring of dam or foundation deformation must be done in a manner such that the displacement is measured both horizontally and vertically (i.e., measurement along horizontal and vertical lines). Such measurements must include the foundation and extend as far as possible into it. Redundancy is essential in this form of deformation monitoring and is achieved through measuring at the points intersecting the orthogonal lines of the deformation network. If a dam includes inspection galleries and shafts, deformation values along vertical lines can be obtained by using hanging and/or inverted plumb lines and along horizontal lines by traverses--both of these methods are standard practice for deformation monitoring. Where there are no galleries or shafts (e.g., embankment dams, thin arch dams, or small gravity dams), the same result can be achieved by an orthogonal network of survey targets on the downstream face. These targets are sighted by angle measurements (typically combined with optical distance measurements) from reference points outside the dam.

d. Relative displacement observations. A more routine, less costly, and more frequent monitoring process can be employed to monitor the short term behavior of dams by simply confining observation to trends at selected points along the crest and sometimes vertical lines. Such procedures typically involve simple angle measurement or alignment (supplementing the measuring installation) along the crest to determine horizontal displacement, and elevation determination by leveling to determine vertical displacement (i.e., settlement). Even with this monitoring process, it is essential to extend leveling to some distance beyond the abutments. Alternative methods to that described include settlement gauges, hose leveling devices, or extensometers.

1-8. Life Cycle Project Management

As outlined in ER 1110-2-100, structural stability assessment surveys may be required through the entire life cycle of a project, spanning decades in many cases. During the early planning phases of a project, a comprehensive monitoring plan should be developed which considers survey requirements over a project's life cycle, with a goal of eliminating duplicate or redundant surveys to the maximum extent possible. During initial design and preconstruction phases of a project, reference points should be permanently monumented and situated in areas that are conducive to the performance of periodic monitoring surveys. During construction, fixed monitoring points should be established on the structure at points called for in the comprehensive monitoring plan.

1-9. Metrics

Both English and metric (SI) units are used in this manual. Metric units are commonly used in precise surveying applications, including the horizontal and vertical survey work covered in this manual. Structural movements are usually recorded and reported in SI units. Some measurement instruments (e.g., micrometers) use English units. In all cases, the use of either metric or non-SI units shall follow local engineering and construction practices. Accuracy standards and tolerances specified in this manual are generally stated at the 95% confidence level.

1-10. Trade Name Exclusions

The citation or illustration in this manual of trade names of commercially available survey products, including other auxiliary surveying equipment, instrumentation, and adjustment software, does not constitute official endorsement or approval of the use of such products.

1-11. Abbreviations and Terms

Engineering surveying terms and abbreviations used in this manual are explained in the Glossary.

1-12. Mandatory Requirements

ER 1110-2-1150 (Engineering and Design for Civil Works Projects) prescribes that mandatory requirements be identified in engineer manuals. Mandatory requirements in this manual are summarized at the end of each chapter. Mandatory accuracy standards, quality control, and quality assurance criteria are normally summarized in tables within each chapter. The mandatory criteria contained in this manual are based on the following considerations: (1) dam safety assurance, (2) overall project function, (3) previous Corps experience and practice has demonstrated the criteria are critical, (4) Corps-wide geospatial data standardization requirements, (5) adverse economic impacts if criteria are not followed, and (6) HQUSACE commitments to industry standards.

1-13. Proponency and Waivers

The HQUSACE proponent for this manual is the Engineering and Construction Division, Directorate of Civil Works. Technical development and compilation of the manual was coordinated by the US Army Topographic Engineering Center (CEERD-TS-G). Comments, recommended changes, or waivers to this manual should be forwarded through MSC to HQUSACE (ATTN: CECW-EE).